DESIGN, FABRICATION & TESTING OF WATER CHANNEL

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ABSTRACT

Fossil fuel generates most of the energy in Malaysia. However, oil and gas in Malaysia are depleting now. Government of Malaysia has been identified renewable energy as fifth fuel under New Five-Fuel Diversification Strategy. Tidal energy is a renewable energy, which is also pollutant free, predictable, and has huge energy density. The scene of tidal energy extraction can be investigated through small-scale model using a water channel. In order to simulate tidal energy extraction, dimensional analysis method is used when designing the water channel. Pump of maximum flow rate $0.0125m^3/s$ at 2m head is used. After fabrication, the water channel is tested to ensure it fulfill the design requirement. The vertical velocity profiles are also investigated by current meter and compare to the vertical velocity profiles of real tidal field. After testing, the water channel shows that it approaches the vertical velocity profiles of real tidal field at certain flow rate.

ABSTRAK

Kebanyakan tenaga di Malaysia dihasilkan oleh bahan api fosil. Walau bagaimanapun, petroleum dan gas asli di Malaysia semakin berkurangan sekarang. Kerajaan Malaysia telah mengenal pasti tenaga boleh diperbaharui sebagai bahan api kelima di bawah Strategi Kepelbagaian Lima Bahan Api. Tenaga pasang surut adalah tenaga boleh diperbaharui, yang merupakan pencemar percuma, diramal, dan mempunyai ketumpatan tenaga yang besar. Keadaan pengeluaran tenaga pasang surut boleh disiasat melalui model kecil-kecilan dengan menggunakan saluran air. Dalam usaha untuk meniru pengeluaran tenaga pasang surut, kaedah analisis dimensi digunakan apabila mereka bentuk saluran air. Pump maksimum kadar aliran 0.0125 m^3/s di kepala 2 m digunakan. Selepas fabrikasi, saluran air diuji untuk memastikan ia memenuhi keperluan reka bentuk. Profil halaju menegak juga disiasat oleh meter aliran air dan dibandingkan dengan profil halaju menegak di tempat pasang surut sebenar. Selepas ujian, saluran air menunjukkan bahawa ia menghampiri profil halaju menegak di tempat pasang surut sebenar pada kadar aliran tertentu.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

F_d	Tidal force
G	Gravitational constant
M	Mass of body
R_e	Radius of the Earth
d	Distance between Earth with the body
v_p	Velocity of prototype
v_m	Velocity of model
a_p	Acceleration of prototype
a_m	Acceleration of model
F_p	Forces on prototype
F_m	Forces on model
Π	Non-dimensional parameter
u_i	Velocity in 3 dimensions, u, v, w
t	Time
p	Pressure
ρ	Density
μ	Dynamic viscosity
L	Independent length scale
V	Independent velocity scale
τ	Independent time scale
P	Power
D	Diameter of turbine

ω	Angular velocity
v	velocity
C_p	Power coefficient
Re	Reynolds number
TSR	Tip speed ratio
A_1	Cross section area of upstream stream tube
A_d	Area of actuator disk
A_2	Cross section area of the downstream stream tube
$U\infty$	Free stream velocity
U_2	Far wake velocity
U_d	Velocity at actuator disk
R_h	Hydraulic radius of the channel
V_c	Average liquid velocity at cross section
g	Gravitational acceleration
L_c	Characteristic length
z	Elevation head
y	Gauge pressure head
Ac	Cross section area
H	Total head of water channel
E_c	Specific energy of water channel
b_c	Width of cross section
f	Darcy friction factor
x	Distance at x direction
S_f	Frictional slope along the channel
S_o	Bottom slope along the channel

v_{max}	Maximum flow velocity taken at the surface
$y_{channel}$	Bed-normal distance measured upwards from the profile datum
h	Flow depth
$1/m$	Power law exponent or index
Fr	Froude number
L_p	Length of pipe
$L_{channel}$	Length of channel
$h_{L,\,pipe}$	Head loss in pipe
K	Loss coefficient
D_p	Diameter of pipe
Q	Volume flow rate
$h_{L,channel}$	Head loss in channel
P_c	Wetted perimeter
$h_{L,Total}$	Total head loss
$H_{required}$	Required head for pump
α	Kinetic energy correction factor
P_S	Surge pressure
D_i	Inner diameter
E	Modulus elasticity of pipe material
T_p	Wall thickness of pipe
P_T	Total pressure
P_{Static}	Static pressure
F	Force
$\dot{m}$	Mass flow rate

LIST OF ABBREVIATIONS

RE	Renewable energy
MHWS	Mean high water spring
MLWS	Mean low water spring
MCT	Marine Current Turbine
RTT	Rotech Tidal Turbine
POM	Princeton Ocean Model
TPXO	OSU TOPEX/POSEIDON Crossover
EES	Engineering Equation Solver

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Most of the energy in Malaysia is generated by fossil fuel. However, according to Haris and Omar's study, oil in Malaysia would be finished by 2015 and gas would be finished by 2048 (Lee & Seng, 2008). Malaysia would become a net energy importer when oil in Malaysia is depleted. Energy consumption in Malaysia also keeps increasing due to the development of the country. Malaysia has been introducing New Five-fuel Diversification Strategy in order to solve this energy issue. Renewable energy (RE) has been identified and finalized by the government as the fifth fuel under the New Five-Fuel Diversification Strategy (Al-Amin et al. 2009)

Tidal energy is a renewable energy. The tidal power plant is pollutant free. Tidal is predictable and has huge energy density (Sun, 2008). However, tidal energy technology is still very fresh to Malaysia. The research about tidal energy in Malaysia is very few (Lim & Koh, 2009). Therefore, more researches are going to do in recent future. In future, tidal energy most likely will be harnessed by tidal turbine farm, like wind turbine farm today (Bahaj et al. 2007). The effect of tidal turbine to the tidal current must be known before start building the tidal turbine (Sun, 2008). This is convenient and cost saving to simulate the tidal energy extraction in small-scale model first before building a prototype. In doing this, a water channel that able to simulate the tidal energy extraction has to be built.

1.2 PROBLEM STATEMENT

It is possible that the tidal turbine farm is used to harass the tidal energy in future. The effect of tidal turbine to the tidal current must be known in order to determine the best orientation of tidal turbines inside the farm (Bahaj et al. 2007). The scene of tidal energy extraction must also be investigated so that it would not raise any environment and safety issues in future (Sun, 2008). It is possible to investigate the tidal energy extraction in small-scale. However, a water channel that has the capability to simulate the tidal energy extraction is needed for doing this.

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1.3 OBJECTIVES OF STUDY

The objectives of this study is designing, fabricating and testing a water channel that able to simulate the tidal energy extraction in Malaysia.

1.4 SCOPES OF STUDY

a) Study on tidal in Malaysia.

b) Dimensional analysis on tidal energy extraction.

c) Pump of maximum flow rate 0.0125 m^3/s at 2 m head is used.

d) Design and fabricate water channel.

e) Experimentally analysis on flow profile of water channel.

1.5 SIGNIFICANCES OF THE STUDY

Fossil fuel in Malaysia is depleting now. Therefore, it is the time for Malaysia to look for new energy resources. Tidal energy has a huge potential because it is a renewable energy and is predictable. It is important to build a water channel that can simulate the tidal energy extraction so that more research can be conducted to this field.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss about the tidal, methods in harnessing tidal energy and tidal energy potential in Malaysia. After discussing about the tidal and tidal energy, this chapter will discuss about dimensional analysis method and scaling methods of tidal energy extraction. After that, this chapter will discuss about the water channel design and properties of open channel flow.

2.2 TIDAL

Vertical rise and fall of seawater is call tide while the horizontal water flow that causes the tide is called tidal current. When the tide rises, the tidal current floods the area. When the tide falls, the tidal current ebbs from the area.

Tidal forces caused by the gravitational force of the Sun and moon, and the earth rotation. Therefore, the tides on the earth are never-ending and predictable (Hassan et al. 2012). Newton's law of gravitation is used to calculate the force caused by the gravitational attraction between the earth with the moon and earth with the sun. Newton's second law of motion can be used to calculate centrifugal force produced on the earth by the earth's rotation. The tidal force of any location of the earth can be calculated by combining Newton's law of gravitation and Newton's second law of motion. The combined formula is as following (Services):

$$F_d = \frac{GMR_e}{d^3} \qquad (2.1)$$

From this formula, one can know that tidal force is inversely proportional to cube of the distance between the mass and earth. Because of this, sun's effect on tidal is only 46 percent of the moon's effect.

There are many types of tide on the earth due to the different geometry of each location. Semidiurnal tide means there are two high tides and two low tides each day. The tidal cycle of semidiurnal tide is 12 hours 25 minutes. Diurnal tide means only one high tide and one low tide each day. The tidal cycle of diurnal tide is 12 h 24 min. Mixed tide is the combination of semidiurnal and diurnal tides (Services; Lim & Koh, 2009).

The tidal range is the difference between high tide and low tide. The tidal ranges vary according to the location of the moon and the sun. When new moon and full moon, the earth, moon, and Sun are on the same line. Therefore, the resultant tidal force is very strong; the tidal range becomes larger than usual. This tide is called spring tides. In first quarter and third quarter, the tidal force caused by the moon is at right angles to the tidal force caused by the sun, the tidal range becomes smaller. This is called neap tide (Services).

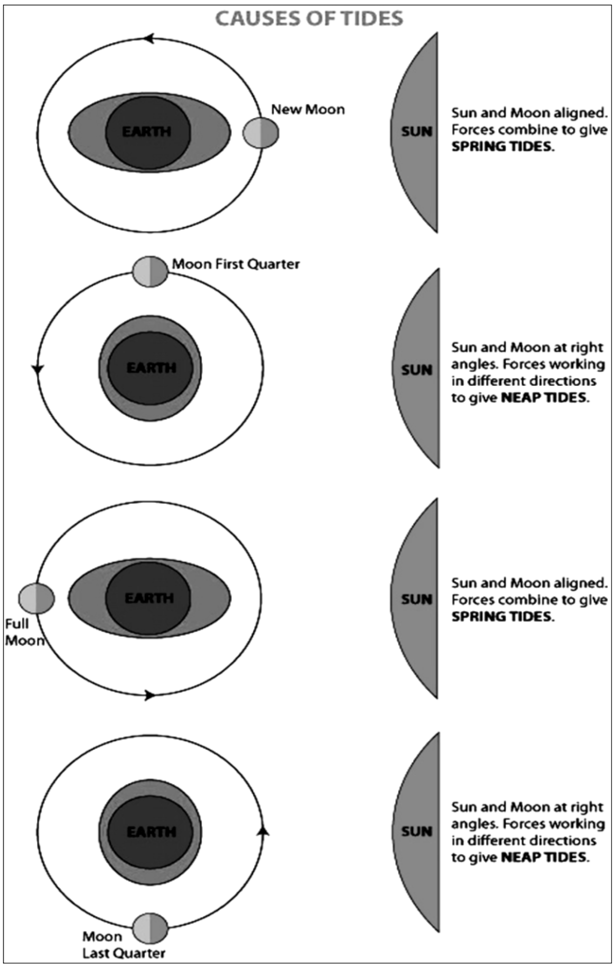


Figure 2.1: Causes of tides

Source: Hassan et al.(2012)

2.3 TIDAL ENERGY

Global climate change is becoming serious. Tidal has huge amount energy and is a pollutant free energy resource. Renewable energy like solar and wind energy is unpredictable. Tidal is predictable and therefore it is more reliable. Tidal energy also reduces the fuel cost because it does not need any fuel (Denny, 2009). Tidal barrage and tidal current turbine are the methods to extract energy from tidal (Rourke et al. 2009).

2.4 TIDAL BARRAGE

Tides cause the variations in ocean level. A barrage is built to impound the water during high tide, and release it during the period of the tide recedes. The water flow through hydraulic turbines installed in the barrages before it flow out to the ocean. Open sea has the small average tidal fluctuations; the geometry of a place can significantly magnify the tidal fluctuations. For example, Cobequid Bay located in Fundy Bay can reach a 16 m swing during high tides. Water that moved in the tides of Fundy Bay is around 100 cubic kilometers per day, this is equals water discharged by all the rivers in the world (Rosa, 2009). A reversible water turbine can be used to generate electricity. This enables barrage to generate electricity at ebb and flood. However, building a tidal barrage is very costly and need a lot of time. Tidal barrage can cause some environmental issues. According to I. Ball study, the tidal barrages can reduce the mudflats needed by the birds (as cited in Sun, 2008). The tidal barrages also block the path of migratory fish, such as salmon and eels (Sun, 2008).

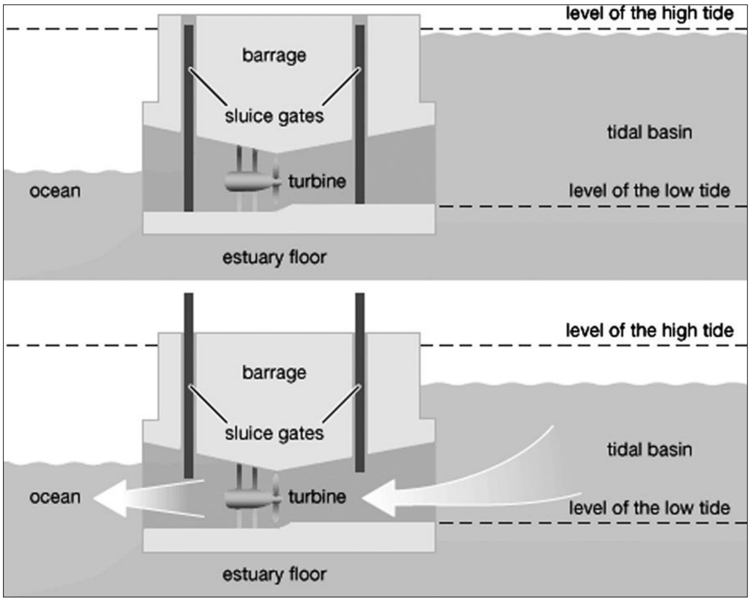


Figure 2.2: Design of tidal barrage

Source: Hassan et al. (2012)

2.4.1 Tidal Barrage In Malaysia

Sejingkat, Perlabuhan Klang, Pulau Langkawi, Tawau, Kutup and Johor Bahru are the six sites with the highest tidal range in Malaysia (Lee & Seng, 2008).

Table 2.1: Tidal range (MHWS – MLWS) of year 2005 for the six highest sites in Malaysia

Tidal Station	Tidal range (m)
Sejingkat	4.38
Perlabuhan Klang	4.2
Pulau Langkawi	2.5
Tawau	2.9
Kutup	2.6
Johor Bahru	2.6

Source: Lee & Seng (2008)

A Fluent model is used to simulate the tidal barrage at these six sites. The speed gained in simulation results are used to calculate the power available at the sites (Lee & Seng, 2008). They obtained the results as below:

Table 2.2: Power availability for six sites using barrage approaches

Date	Monthly Availability (%)					
	Sejingkat	Perlabuhan Kelang	Pulau Langkawi	Tawau	Kukup	Johor Bahru
Jan	76.10	76.41	60.01	64.45	65.86	62.95
Feb	75.80	74.53	63.73	63.70	66.84	61.00
Mar	75.16	74.53	60.95	65.62	66.58	60.57
Apr	76.18	75.10	57.44	61.67	65.11	62.10
May	76.15	75.88	57.52	61.08	63.35	63.65
Jun	74.97	76.91	61.54	66.44	67.25	64.31
Jul	76.07	76.01	57.26	62.37	67.94	62.89
Aug	76.61	74.40	57.76	62.63	64.85	62.74
Sep	76.39	74.01	59.69	66.38	68.67	63.64
Oct	75.83	74.19	61.63	62.67	63.71	65.77
Nov	77.61	75.24	60.66	63.07	62.24	65.89
Dec	76.91	76.96	59.48	64.05	65.58	64.50

Average	76.15	75.35	59.81	63.68	65.67	63.33

Source: Lee & Seng (2008)

Sejingkat show the highest average, which is 76.15 %. Perlabuhan Kelang also has an average of 75.35 %. All locations has the average of beyond 55 %, this show that the potential sites of building a tidal barrage can be found around Malaysia (Lee & Seng,2008).

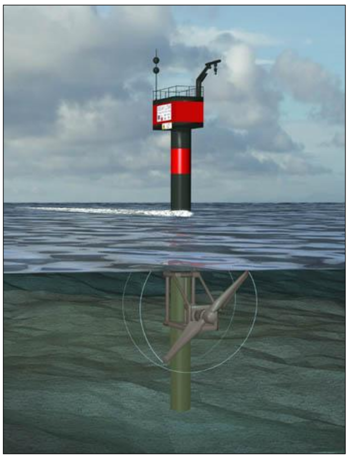
2.5 TIDAL CURRENT TURBINE

Different with tidal barrage which use the potential energy between high and low tides, tidal current turbine use the kinetic energy of moving water to generate electricity (Rourke et al. 2009)

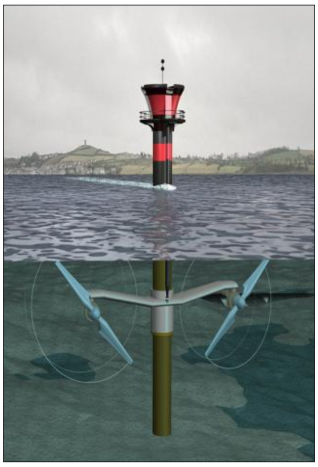
Many tidal current turbine prototypes are being built and tested in the ocean. In the future, these tidal turbines might be built in array like wind farms. Tidal is predictable and water is 832 times denser than air. These all make the tidal energy more reliable than wind energy. The tidal turbines rotate either in horizontal axis or in vertical axis (Rosa, 2009).

2.5.1 Horizontal Axis Tidal Turbine

Marine Current Turbine Ltd (MCT) has built a prototype called Seaflow rated at 300 kW. This single rotor turbine generates an average power of 100 kW and has a rotor diameter of 11 m. Then, in 2006, a 1.2 MW prototype Seagen was built. Seagen has the twin axial open rotors (Rosa, 2009). The photo of both Seaflow and Seagen are shown below.



(a)



(b)

Figure 2.3: Marine Current Turbine (a) Seaflow (b) Seagen

Source: (a) http://tpe.energiesdelamer.free.fr/hydrolienne.html#intro
(b) http://www.alternative-energy-news.info/seagen-tidal-power-installation/

Besides MCT, Lunar Energy Ltd, a Britain tidal power company developed Rotech Tidal Turbine (RTT). Asymmetrical duct is installed to increase the speed of the flow in RTT design. The full-scale prototype is aimed to generate 1MW of electricity. However, RTT 2000 is designed to generate 2 MW from a 3.6 m/s surface tidal current (Previsic, 2006). According to news released on Luner Energy Ltd website at 2008, Lunar Energy Ltd has received a deal to install 300 tidal current turbines at Korea with the cost 500 million pounds (Rourke et al. 2009).